SKILLED RIDERS MANAGE HORSE GAIT COMPLEXITY THROUGH A GAIT TRANSITION WHILST ALSO MAINTAINING STABLE HORSE-RIDER COORDINATION VARIABILITY

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Equestrian riders aim to cue smooth transitions between horse gaits. This study aimed to investigate whether competitive horse rider (n=10) decrease horse gait regularity and increase horse-rider coordination variability in the region of a gait transition (n=6; both walk-trot, and trot-canter) relative to baseline walk, trot and canter. Resultant accelerations from IMUs affixed to the horse's girth and rider's pelvis were calculated. Horse gait regularity was quantified as multiscale sample entropy (MSSE) of the pelvis. Horse-rider coordination variability ($Coord_{var}$) was quantified as the standard deviation of the horse-rider continuous relative phase. Pre-transition MSSE did not increase; post-transition MSSE significantly decreased (paired t-tests; $p<0.05$). No significant differences in $Coord_{var}$ were found. Therefore, horse gait or horse-rider $Coord_{var}$ does not increase in a transition.

KEYWORDS: Multiscale sample entropy, continuous relative phase

INTRODUCTION: Equestrian sport relies on the effective coordination between the two complex biological systems of the horse and rider. In a sporting context, such as dressage, the horse-rider combination is judged on the rider's ability to maintain the rhythm and regularity of the horse's stride, whilst performing movements such as changes in direction and gait. Horses possess three main gait patterns involving differing interlimb coordination. The slowest gait, walk, has a lateral sequence of hoof placements. The trot is a running gait with alternating paired diagonal hoof placements, with an intervening suspension phase. The canter is a leaping gait with asymmetric hoof placements initiated with a rear leg, followed by a diagonal pair, prior to a lead forefoot. Transitions between gaits are performed during training and are scored during competition. The rider cues the horse to perform a transition on-demand with cues from their legs, seat, and reins. Unridden horses naturally perform transitions to faster gaits (upward transitions, such as a walk to trot, or trot to canter) at a critical velocity threshold that maximizes metabolic economy (Farley et al, 1991; Griffin et al, 2004). It is theorized that increased variability of limb coordination precedes gait transitions in the unridden horse (Schöner, Jiang and Kelso, 1990). Riders, however, aim to maintain consistent stride regularity of the horse's gait until the point of transition, therefore controlling the horse to maintain a consistent velocity and perform a smooth transition. The horse's trunk motion is influenced by their limb sequences and can be used for gait identification, using a single trunk-mounted IMU (Viry et al, 2013). Therefore, limb coordination variability in the region of a transition would be reflected by increased variability of trunk motion. Horse trunk acceleration, in combination with a complexity measure such as multiscale sample entropy (Yentes and Raffalt, 2021), can provide ecologically valid insight into the regularity of the ridden horse's gait during transitions. As a rider cues a horse to perform the transition, horse-rider coordination is pertinent as increased rider coordination variability can increase horse gait variability (Lagarde et al, 2005). It is possible that horse-rider coordination variability is related to horse gait regularity, and that competent riders do not increase horse-rider coordination variability when performing a task, such as a transition.

The aim of this study was: (1) to examine if horses, ridden by competitive riders, maintain similar levels of gait regularity prior to and following an upward transition (walk-trot and trot-canter), relative to baseline walk, trot and canter, (2) to examine whether transition gait regularity is related to transition horse-rider coordination variability, and (3) whether riders maintain similar levels of horse-rider coordination prior to and following a transition to baseline.

It is hypothesized that competitive riders will not decrease horse gait regularity during a transition and that gait regularity will be related to horse-rider coordination variability. Finally, it is hypothesized that riders will not increase horse-rider coordination variability prior to and following a transition.

METHODS: Ten competitive riders (age: 24 ± 9 y, height: 1.65 ± 0.7 m, stature: 65 ± 11 kg) affiliated to the national equestrian federation rode their own horses. Two IMUs (IMeasureU, Vicon, Oxford, UK) were affixed to the horse's girth and the rider's sacrum, sampling at 800Hz to a handheld device. Riders rode five times in walk, trot, and left canter on a 40 m straight track in an indoor arena (baseline), and then performed six walk-trot and trot-left canter transitions at the 20m mark. Sensor data were extracted and automatically down sampled to 250 Hz due irregular sampling frequencies caused by Bluetooth transmission. A custom MATLAB (The MathWorks, Natick, MA, USA) script was used for all subsequent processing. The resultant accelerations were calculated for each trial, mean-centered, and low-pass filtered with a 30 Hz cut-off. The middle 6 seconds of the baseline trials were extracted for analysis. Strides were identified by peak accelerations characterizing stance phases in each gait using smoothed (10 Hz cut-off) vertical acceleration of the horse IMU (as per Viry et al, (2013)). This protocol was applied to the transition trials to identify four strides on either side of the transition area.

Multiscale sample entropy (MSSE; Costa et al, 2002) was used to obtain a measure of the complexity of the resultant acceleration of the horse's trunk pre- and post-transition. Briefly, MSSE calculates the sample entropy of an increasing coarse-grained signal which is calculated by averaging the data points in non-overlapping windows of length τ, where τ is the time factor (Richman and Moorman, 2000). The sample entropy algorithm requires a minimum of 200 data points for acceptable levels of relative reliability (Yentes et al, 2013), therefore time factors 1-6 were used ([250 Hz × 6 s]/6 = 250 data points). Vector length was set as m = 2, and tolerance (r) was set at 0.2x the windowed standard deviation (Gow et al, 2015) to minimize the effect of non-stationarity of the signal on the tolerance level.

Coordination was quantified as the continuous relative phase (CRP) between the resultant acceleration of the horse and the rider's pelvis, using the Hilbert transform as described by Lamb and Stöckl (2014). The CRP was calculated prior to stride segmentation. Horse-rider coordination variability ($Coord_{var}$) was then calculated for each trial as the mean of the circular standard deviation of the four baseline, and four pre- and post-transition strides.

Differences between baseline and both pre- and post-transition MSSE, as well as baseline and pre- and post-transition coordination variability, respectively, were assessed using paired t-tests in SPSS (IBM, Armonk, NY, USA). The relationship between transition MSSE and transition coordination variability was assessed using Pearson's correlation coefficient. The level of significance for all tests was set *a priori* at $p = 0.05$.

RESULTS: Descriptive statistics of baseline and transition horse MSSE and horse-rider $Coord_{var}$ are presented in Table 1. No significant differences were found between pre-transition MSSE relative to baseline (walk $t = -0.83$, $p = 0.426$; trot $t = 1.40$, $p = 0.20$). However, MSSE significantly decreased in post-transition gaits relative to baseline (trot $t = 3.22$, $p = 0.01$; canter $t = 1.40$, $p = 0.006$). No significant differences were found between baseline and transition coordination variability for any gait (walk $t = -2.08$, $p = 0.067$, and trot $t = 2.19$, $p = 0.056$ for walk-trot; trot, $t = 0.995$, $p = 0.346$ and canter $t = -1.03$, $p = 0.330$ for trot-canter). No significant correlations were found between transition MSSE and transition coordination variability (Figure 1).

Table 1: Multiscale sample entropy (MSSE) and horse-rider coordination variability ($Coord_{var}$) means ± standard deviation for baseline and transition (walk-trot, trot-canter) trials. Starred values indicate transition values that were significantly different to baseline values ($p < 0.05$).

	Baseline			Walk-Trot		Trot-Canter	
	Walk	Trot	Canter	Walk	Trot	Trot	Canter
MSSE	0.52 ± 0.05	0.57 ± 0.06	0.61 ± 0.05	0.54 ± 0.05	0.48 ± 0.06*	0.53 ± 0.05	0.52 ± 0.07*
$Coord_{var}$	37.0 ± 4.3°	33.6 ± 5.4°	29.4 ± 6.5°	40.8 ± 3.0°	27.2 ± 8.0°	33.1 ± 5.3°	29.5 ± 6.4°

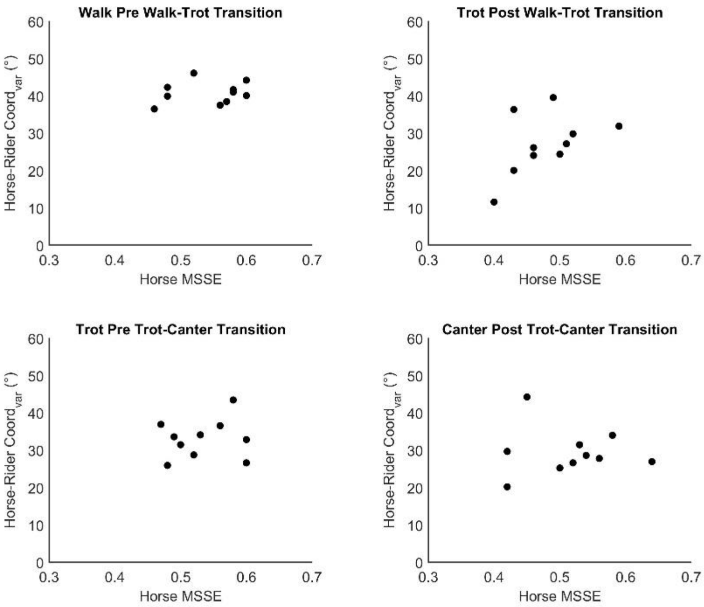

Figure 1. Horse-rider coordination variability ($Coord_{var}$) and horse multiscale sample entropy (MSSE) correlations for pre-post transitions in walk-trot and trot-canter gait transitions.

DISCUSSION: There were no significant differences between pre-transition walk and trot and baseline MSSE or $Coord_{var}$, indicating that regularity of the horse's gait, or horse-rider coordination variability does not increase in the region of a transition in the ridden horse. However, the hypothesis cannot be fully accepted as MSSE post-transition in trot and canter was significantly decreased relative to baseline, showing that the strides immediately following the upward transition display greater regularity than steady-state trot or canter on a straight line. The horse's rhythm and regularity of gait when performing movements, such as transitions, is a judged element in equestrian dressage. These findings reflect the rider's ability to cue a smooth transition, rather than provoking a transition by increasing velocity to the critical threshold. Therefore, competitive horses ridden by skilled riders do not follow the theory proposed by Schöner, Jiang and Kelso (1990), in which transitions are preceded by a loss of stability in the interlimb coordination pattern of the horse. Significant decreases in MSSE reflect the rider's ability to maintain control, ensuring a smooth departure in the new gait. As the riders were competitive, this result may likely relate to their skill and previous training. No previous studies have analyzed horse MSSE, however, the values obtained would suggest that like humans, the horse's gait patterns exhibit inherent regularity.

Interestingly, no significant correlations between transition MSSE and $Coord_{var}$ were found. Therefore, there is no apparent relationship between horse-rider coordination variability and regularity of the horse's gait prior to and following a transition. These findings have interesting implications as it suggests that riders can achieve stable coordination to their individual horse's gait pattern with their pelvis. To cue the transition, riders must use their hands and legs. Skilled riders aim to achieve these cues without disturbing the strength of coupling between their pelvis and the saddle. This is a key performance objective in equestrian, known as the 'independent seat'. Similar coordination variability results and values were found by Wilkins et al (2022), albeit on a riding simulator. Therefore, this study demonstrates the independent seat in competitive riders riding their own horses in an arena during a performance-related task. These results likely reflect rider skill, however, due to the homogeneity of the current cohort, the exact influence of skill is yet unknown. Another limitation relates to the analytical approach. While the state of coordination variability and complexity is determined here, exactly how the riders achieve these parameters is currently unknown. Future research could enhance understanding of how riders manage the horse interaction with supporting kinematic analysis.

As performance in equestrian sport relates to the rider's ability to perform a range of transitions, changes of direction and velocity, while maintaining the horse's gait rhythm and regularity, the present results demonstrate the ability to measure equestrian performance with a single IMU on the horse and rider, respectively. While previous studies have analyzed horse-rider coordination dynamics during simple tasks, such as straight-line locomotion (e.g. Lagarde et al, 2005), these methods and subsequent analysis offer the potential to expand understanding of equestrian performance relating to competition demands.

CONCLUSION: The ridden horse is cued to perform transitions on demand by the rider. Competitive riders aim to perform transitions between gaits without a loss in the horse's rhythm or regularity. In the present case of upward transitions performed by competitive horses and their riders, the pre-transition gait shows similar levels of regularity to baseline trials without a transition. The post-transition displays significantly greater regularity than baseline levels, which aligns with common equestrian practice of using transitions between gaits for training purposes. Riders do not significantly alter the variability of the coordination to the horse in anticipation of a transition or post-transition. Horse and rider performance can be objectively quantified during riding in an arena using two IMUs and resulting analysis can map to performance determinants in equestrian sport.

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